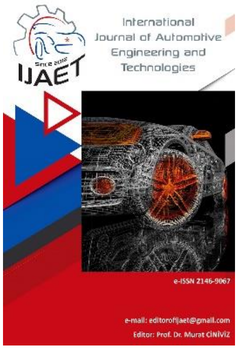
e-ISSN: 2146 - 9067

International Journal of Automotive Engineering and Technologies

journal homepage:

https://dergipark.org.tr/en/pub/ijaet



Original Research Article

Improving level measurement techniques and measurement accuracy in vehicle fuel tanks

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ARTICLE INFO

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Doi: 10.18245/ijaet.1029794

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Received: Nov 29, 2021
Accepted: July 20, 2022

Published: 02 Oct 2022

Published by Editorial Board Members of IJAET

ABSTRACT

Measuring the level and accurate transmission of the amount of fuel in vehicle fuel tanks are important in many ways. In vehicle warehouse designs, very different geometric shapes are encountered. Vehicle geometry and equipment placement cause warehouses to be produced in very different geometries. It is very important that information about the amount of fuel is transmitted to the driver in the most accurate way so that the driving safety and the car can travel safe distances. Shaking the fuel in the tank on a flat road, slope or off-road conditions may affect the display of the correct amount of fuel. In the study, the maximum and minimum production tolerance and geometry of the vehicle tanks, known as the mathematical model, the turbulence caused by acceleration of the float fuel measurement system in contact with the liquid placed in the tank, as well as the accuracy of the Up/Down movement of the level measurement float and the measurement of the fuel level as a result of the turbulence, were examined. The study focused on the oscillation of the measuring part on the float and the preventive geometries.

Keywords: Fuel, Tank, Sloshing, Level Measurement

1. Introduction

Many methods are used for level measurement in vehicle fuel tanks. The important thing here is that the correct measurement can be performed while cruising or standing. Pressure tanks in which the fuel needed for the operation of the car engine is stored are called “fuel tanks”. Liquid contact/non-contact sensors or mechanical solutions can be used to measure the fuel tank level. Vertical movable float systems are usually preferred because they are more cost-effective.

Capacitive level sensors (Figure 1) usually use radio frequency technology. It uses the electrical characteristics of capacitors to detect the level of liquid, granules, cement-like materials in the container. The electrode (probe) in the clothed or naked state is immersed in the tank as the first conductive part of the capacitor. The metal body of the tank, on the other hand, will act as the other conductor. In non-metal and plastic tanks, double-electrode systems should be used in which the second electrode serves as the other capacitor conductor. The capacitive level sensor measures the change in capacity that occurs during the movement (increase or decrease) of the material inside the tank through the sensor probe. This capacity value can also be used for a linear measurement, as well as for obtaining level information at a certain point as a contact output [1].

Figure 1: Capacitive Level Sensor

The principle of operation of inductive level switches (Figure 2) is based on the method of measurement of magnetic field permeability (permeability). It is hardly seen outside of laboratory studies. It is not very practical to monitor the change of the tank impedance, it requires large amounts of energy. On the other hand, it is also possible to measure at least as a switch by changing the operating frequency (resonance frequency) provided by the system formed by the tank. This is also the principle of operation of metal detectors. However, its applicability in level measurement is poor [1].

Figure 2: Inductive Level Switches

Ultrasonic level sensors (Figure 3) use sound waves to detect the level. A piezoelectric crystal in a transducer placed on top of a tank converts non-electrical signals into sound energy that moves in waves through the medium at a certain frequency and constant speed. The sound waves propagate and return to the transducer as an echo. The device simply measures the time elapsed between the wave beginning to propagate and reflecting off the surface and decaying back. This time is directly proportional to the distance between the transducer and the surface of the material to be measured and can be used to measure the level of the material.

Ultrasonic level switches, especially for point level of low viscosity liquids it is an alternative method for measuring. It detects whether there is any material between the converter crystal on one side of the switch and the receiver crystal on the other side, by the method of transmission of sound waves. This method is quite similar to the ultrasonic principle. Radar (Sometimes also called microwave.) in his method, high-frequency electromagnetic waves of the order of GHz are used, which are directed downward from the sensor placed on top of the container. The part of the sent energy reflected from the liquid surface, the level of which is to be measured, returns to the sensor. The commuting time of the signal (also called the flight time.) is the magnitude used for the determination of the level. No tubes or cables are used in the radar technology, which is called Non-Invasive. FMCW (Frequency Modular Continuous Wave) and pulse radar are two different non-invasive radar technologies, invasive radar technology uses a cable or rod extending from the sensor to the bottom of the tank to guide the wave[1].

Figure 3: Ultrasonic Level Sensor

Vibration probes, on the other hand, vibrate using a piezo-electric element located at the end. This piezo-electric element is set to a certain vibration frequency. With any material of the probe upon contact, the vibration is absorbed by the material. This change in vibration is felt by the sensor and converted into a relay output. Single-bar devices are only solid when used in materials, double-probe devices can be used in both liquid and solid materials. Vibration probes are typically placed on the top or side of the tank is mounted. Electronic level switches have two important advantages. The first is that they do not need any calibration for different materials. The second is that these probes can work smoothly even in very low density materials.

Light sensors use simple optical switching. The change in the amount of light in the sensor indicates that the level is at this point. It is not used frequently for level measurements due to the excessive need for maintenance (especially cleaning). Measurement insensitive to reference light change (pollution) is also possible, but its cost is quite high. This measurement method is more useful in pollution measurement applications than level measurement [2].

Level measurement with transparent pipes (Figure 4) basically, the principle of combined containers is used to view the liquid level in the tank. Since the level in the glass pipe mounted on the tank edge and the level of the material inside the tank are the same, the level can be easily monitored from outside the tank. With this method, only visual level control can be performed, since there is no mechanical or electronic interference with the system.

Figure 4: Level Measurement with Transparent Pipes

Level measurement with a diaphragm is usually performed when the lever with a magnet approaches the body with a reed contact or micro-switch under the pressure of the material, and the level of the material is checked with the contact received. It is similar to the float principle, but it is advantageous to use solid materials in level control.

The different studies to be carried out will help both the literature and the employees in the application part of the subject. Below are the summaries of some of the studies related to the subject.

In their studies, Yumurtaci and Yabanova(2018) have refined the working principles of capacitive sensor, ultrasonic sensor, differential pressure transducer and vertical moving float used in liquid level measurement. It has been observed that the pressure and temperature value of the medium and the type of liquid in the tank from the material of the tank to be used and the environment to be used in the measurement of the sensor to be used are effective [3].

Sahbazli(2017) used an ultrasonic sensor to measure the liquid level and performed the level measurement with a sound wave without direct contact with the liquid. It has achieved a successful measurement at levels in the range of 0-30 cm[4].

In other study, the turbulence in the fuel tanks was investigated. Two different tanks with and without curtains were observed with 50%-85% occupancy rates and warnings were given in different directions. In this study, it was seen that the turbulence caused sudden pressure changes. In the webbed tank design, it has been observed that the liquid is effective in reducing the pressure value during the turbulence[5].

A detailed study was conducted on the level measurement methods and Keskin and Saribas(2017) divided them into two groups as mechanical-based and electrical-based. They also used the ultrasonic measurement method to measure the level of liquid in a small tank. They concluded that successful measurement was obtained in the range of 0-20 cm levels in their experimental studies[6].

Theoretical and experimental studies have been carried out according to different design styles, refueling rate and direction of linear movement of the fuel tank for the standard input value of the shaking event in the passenger car fuel tank. Kilic (2015) examined the shaking event by making different designs such as fretless, fretless/float and fretted/float. Kilic(2015) observed that the webbed/float tank structure has a more balanced pressure distribution and dampens turbulent movement[7].

The level control was carried out by processing the analog data obtained with the float and potentiometer. The purpose is for the centrifugal pump to work stably and to maintain the liquid level at the required levels. In the experimental study, fuel level measurement was performed not at all levels, but to the extent necessary to ensure that it exhibits a stable structure [8].

In a thesis study, a mechanical solution with a high-precision servo motor drive that can measure the lifting force of liquids and solids based on is investigated. As with any method, the type and temperature of the substance whose level is measured in this measurement method varies depending on parameters such as the pressure or opening of the tank to the atmosphere, the size and location of the tank. It has been seen that while this application provides high accuracy in measuring liquids, special attention should be paid to parameters such as smooth and accurate assembly in solids[9].

In addition to mechanical measurement methods, it is possible to measure liquid without liquid contact. The accuracy of measurements performed without liquid contact, without adding any measuring substance or device to the liquid, disappears over time and gives erroneous results. In this study, it is aimed to prevent this condition. The measurement system is used in a hybrid form with ultrasonic, temperature and humidity sensors, without being connected to a single sensor, the liquid level is measured, it can also be easily adapted to liquid tanks of different sizes and shapes[10].

2. Material and Methods

In this study, mainly the maximum and minimum production tolerance and geometry of the float fuel metering system in contact with the liquid placed in the tank in on-board tanks known as the mathematical model, the turbulence caused by acceleration and the accuracy of the upward/downward movement of the level metering float and the measurement of the fuel level as a result of the turbulence were examined. Design of the level measuring float part on the float (Figure 5) in an unprotected way together with the initial design works carried out; it has been found in the analysis and design processes that it is very affected by the turbulence that occurs in the fuel tank. In particular, it has been found that the turbulence level is too high in models with complex tank geometry (asymmetric), and when the vehicle is accelerated suddenly, the fuel fluid in the tank hits the float part with a shock effect (Figure 6).

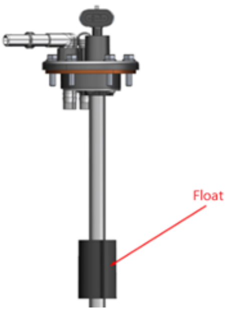

Figure 5: The Float Part of the Level Measurement

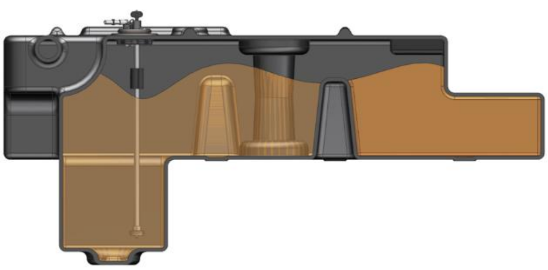

Figure 6: The Effect of Turbulence on the Level Meter

Another method is the breakwater mechanism to be added to the fuel tank (Figure 7). Parts of the fin structure that will be placed in the tank during the manufacture of a fuel tank can somewhat protect the float part in cases of sudden turbulence. However, this manufacturing method may not be suitable both from a technical point of view, from a production point of view, and from a cost point of view. Since the manufacturing processes of fuel tanks are produced with fairly large molds, it can be quite difficult to put the breakwater parts in the mold. It is hardly possible to add breakwater parts externally after manufacturing. In addition, even if the breakwater parts are somehow added to the tank, the distance to the float part will be far away, and it will not be able to restrict the turbulence at the expected levels over a large volume. In this case, it will still be affected by float turbulence and will be able to make level measurement errors.

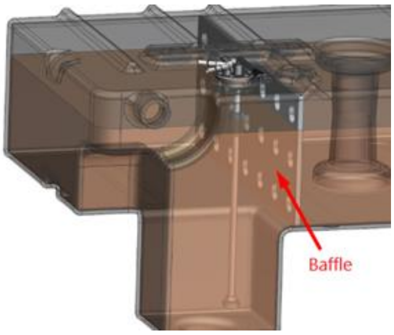

Figure 7: Breakwater Mechanism

In order to avoid such situations and reduce error modes to zero, it is possible to carry out a filtration design mechanically. In the current design, the float part is located in an unprotected structure on the float and therefore it can be affected very much by the turbulence. With the design made, a piece of housing was thought out around the float and it was aimed to reduce these error modes to minimum levels by producing the housing to be monolithic with the float. This designed housing part (damper unit) takes the float on the float into a reservoir, creating a closed volume and protecting it from sudden turbulent effects (Figure 8).

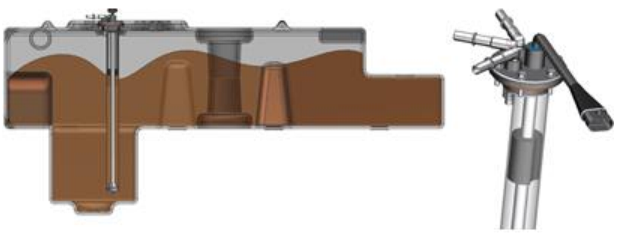

Figure 8: The Structure of the Housing Part on the Tank

However, in order for the float part to float in the fuel, small holes are also needed at the bottom of the housing part so that there is a fuel inlet into the closed volume through these holes and the float can continue to float in the liquid (Figure 9).

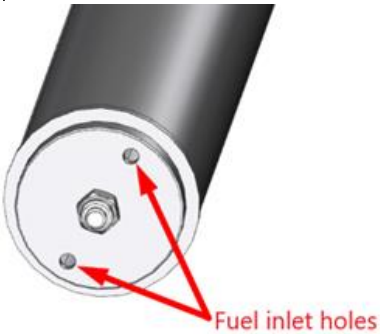

Figure 9: Placement of Fuel Inlet Holes on the Part

The dimensions of the housing part must be designed in accordance with the dimensions of the float part. The inner diameter and outer diameter of the housing part should be determined by conducting tolerance analyses of the outermost diameter dimension and inner diameter dimensions of the float part and applying code chain calculation. Otherwise, the float may overlap/rub with the inner diameter of the housing part and make an incorrect fuel level measurement. In addition, the vacuum-forming state of the casing part protection should also be evaluated in this mechanical filtration method. There should also be holes on the housing part with the same dimensions of the holes drilled to ensure the entry of fuel into the closed volume, as well as in areas where the maximum fuel level is Figure 10.

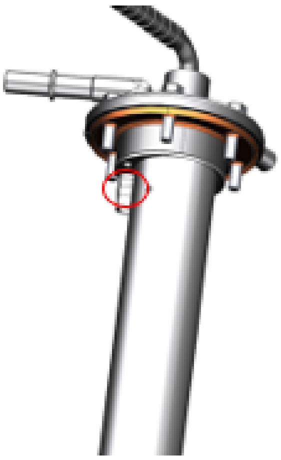

Figure 10: Damper Breathing Hole

Otherwise, if there is no hole drilled on the top side, there will be no air intake into the closed volume, as the fuel level decreases, the fuel level in the closed volume will decrease very slowly, that is, it will vacuum. In this case, incorrect level measurement information will be read from the float.

3. Results

As a result of the unprotected design of the float level measurement part on the float together with the initial design studies, it was found in the analysis and design processes that it was very affected by the turbulence that occurred in the fuel tank. In particular, it has been found that the turbulence level is too high in models with complex tank geometry (asymmetric), and when the vehicle is accelerated suddenly, the in-tank fuel liquid hits the float part with a shock effect. The tests were carried out in two ways, with the float part connected to the fuel level measurement sensor free and in direct contact with the liquid, and by passing a protection part out of the float. Two types of protected and unprotected fuel level sensors were tested under the same conditions and under the same turbulent effects by placing 25, 50, 75 and 90 liters of fuel in the tank, respectively(Figure 11). The resistance change due to the movement of the float part during the shaking was recorded with the Arduino. Each combination was tested for 1 minute. Output resistance values were transferred to the computer environment and the measurement differences between two types of fuel level sensors were observed. The outputs of protected and unprotected fuel level measurement sensors performed at 10, 20 and 25 RPM with different volumes of liquid are shown in Table 1.

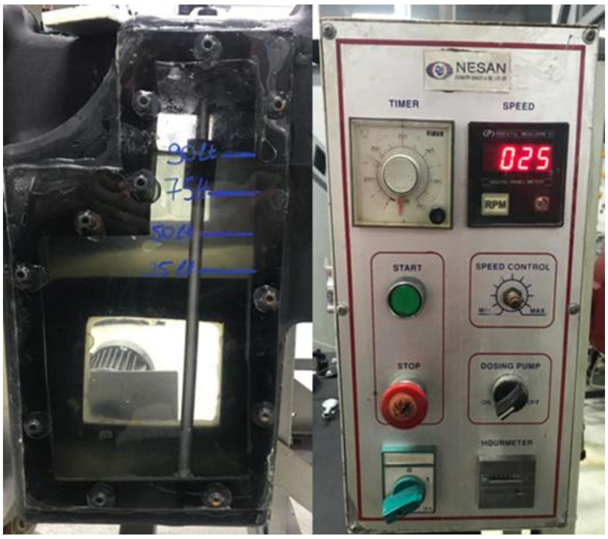

Figure 11: Tank Volumes and Speedometer

In such cases floatin too much upward/downward moves and hence the lack of sensitivity in the measurement of level and faulty measurements by making vehicle electronic control unit (ECU) that sends the wrong level of analysis and design information in the environment have been identified. This incorrect information gives the user incorrect fuel level display information on the vehicle ECU, but it can also cause the hand on the level indicator to move up/down continuously. This error mode a delay can be created using the 'delay' function on the software on the car ECU. In this case, an intermittent measurement is made for the duration of the "delay", not by taking a continuous data over the float. According to this method, the movements of the float part can be somewhat deafened. However, in the deafening technique performed with this method, the float can also give incorrect level measurement information to the vehicle ECU in some cases. Because, no matter how infrequently the measurement frequency is performed, in extremely turbulent situations, the up/down movement of the float can be captured at the wrong position point and incorrect level measurement information can be sent to the ECU.

The raw material details of the designed damper unit part are also important. Because it will constantly come into contact with the fuel fluid, a raw material with a high corrosion resistance should also be selected. In addition, the inner diameter measurement and outer diameter measurement of the damper unit part will be designed depending on the float and float sensor head, so the wall thickness will also be thin. (the range of 1-2 mm. In this context, it is appropriate to prefer aluminum raw materials, preferably aluminum 6061 or 6063 (tempered at T6 level) supports the design in a rigid structure[12].

CRediT authorship contribution statement

Öner ATALAY: Interpretation of experiments, manuscript writing/editing, journal correspondence
Buse BELLİ: Experimental design, analysis of experiments, literature review, graphical design
Oğuz SEZGİN: Experimental design.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This article is produced from MSc. thesis of Buse BELLİ. This study is supported by Pamukkale University Scientific Research Projects(2020FEBE053) and NESAN Automotive Company.

Table 1: The outputs of protected and unprotected fuel level

Tank Volume (L)	Application Type	Min. (Ohm)	Max. (Ohm)
25	Unprotected/ 10 RPM	59.38	77.04
	Protected / 10 RPM	61.56	62.62
	Unprotected / 20 RPM	60.47	77.04
	Protected / 20 RPM	61.56	62.65
	Unprotected / 25 RPM	43.35	77.04
	Protected / 25 RPM	60.47	65.94
50	Unprotected/ 10 RPM	75.92	92.99
	Protected / 10 RPM	91.83	92.99
	Unprotected / 20 RPM	75.92	108.23
	Protected / 20 RPM	91.83	99.97
	Unprotected / 25 RPM	75.92	108.23
	Protected / 25 RPM	91.83	92.99
75	Unprotected/ 10 RPM	108.23	122.69
	Protected / 10 RPM	108.23	109.42
	Unprotected / 20 RPM	77.04	122.69
	Protected / 20 RPM	107.04	122.69
	Unprotected / 25 RPM	91.83	136.28
	Protected / 25 RPM	108.23	109.42
90	Unprotected / 10 RPM	137.53	195.52
	Protected / 10 RPM	136.28	137.53
	Unprotected / 20 RPM	132.54	278
	Protected / 20 RPM	136.28	192.75
	Unprotected / 25 RPM	126.36	341.9
	Protected / 25 RPM	137.53	223.9

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